

DESIGN AND TEST OF AN ELECTRIC
FURNACE PYROMETER

BY

THEODORE C. SEDGWICK

ARMOUR INSTITUTE OF TECHNOLOGY

1921

536.52
Se 2

AT 603

Sedgwick, Theodore C.

Design and test of an
electric furnace pyrometer

Digitized by the Internet Archive
in 2009 with funding from
CARLI: Consortium of Academic and Research Libraries in Illinois

DESIGN AND TEST OF AN ELECTRIC
FURNACE PYROMETER ²²⁰³/₂₂

A THESIS

PRESENTED BY

THEODORE C. SEDGWICK

TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

BACHELOR OF SCIENCE

IN

MECHANICAL ENGINEERING

JUNE 2, 1921

APPROVED


Professor of Mechanical Engineering

Dean of Engineering Studies

Dean of Cultural Studies

DESIGN AND TEST OF AN ELECTRIC
FURNACE PYROMETER

I N T R O D U C T I O N

According to latest estimates (1920), almost a billion dollars worth of coal is wasted every year in the United States due to inefficient combustion of fuels under steam boilers. The average boiler efficiency is around 50% and could be easily raised to around 70% if the biggest loss due to imperfect combustion could be eliminated.

The problem then resolves itself into finding a method for determining the proper proportioning of air and fuel in the furnace. This method must be simple enough for the fireman to follow, and the more independent the device used, as a guide is of local conditions the more its practicability.

Now, if the temperature of the furnace, or rather of the gases leaving the furnace, be studied, it will be found that the closer the amount of air used for combustion is to theoretical requirements the higher will the furnace temperature be. In fact, as will be shown later, for all fuels satisfying the condition that they require 7.5 lbs. of air or thereabouts for each 10,000 Btu. of their heat value, there is a definite maximum temperature for the gases in the furnace for perfect combustion. If 200% air

is used, the temperature of the furnace will be about half its maximum, and, in general, the temperature will be practically ~~i~~ inversely proportional to the relative amount of air used.

The furnace temperature is, therefore, a guide to combustion efficiency. Thus suppose that it is desired to avoid clinker ~~in~~formation and the burning out of arches, so that a furnace temperature of 2000 °F is decided upon as the ideal one. Then, if for the fuel used, the maximum theoretical temperature is 4000 °F, the chosen temperature corresponds to about 200% air or to a 100% excess. If 7.5 lbs. of air is the theoretical requirement for 10,000 Btu., and if the boiler room and flue gas temperatures are, say, 80°F and 480°F, respectively, the loss due to excess air, for an average specific heat of .25, is,

$$\begin{aligned}\text{Excess Air losses} &= .25 (7.5+1)(480 - 80) = \\ &= 850 \text{ Btu.}\end{aligned}$$

or

$$100 \frac{850}{1000} = 8.5\%$$

For 200% air, the loss is doubled and is, therefore, increased to 17%. Considering the fact that the usual excess air found in practice is around 300-400%, the losses due to excess air are reduced from

32 or 42.5% to only 17%,

with a resulting saving of about 20%, if the furnace

temperature is maintained at 2000°F by damper regulation with a furnace pyrometer as a guide.

A simple reliable furnace pyrometer would, therefore, make possible tremendous fuel savings, if followed by the fireman. The difficulties of using thermo-couple pyrometers for measuring furnace temperatures are twofold. In the first place the temperatures of the gases in the furnace vary by several hundred degrees from point to point, so that the indications of one thermo-couple in a furnace of say 100 square feet of grate, surface would be meaningless on account of such poor "sampling efficiency".

In the second place, the average thermo-couples are not suited for continuous exposures to temperatures ranging from 2000 to 3500°F.

Optical pyrometers are not satisfactory chiefly because they indicate the temperature of the fuel bed instead of the gas temperature. In fact a variation of about 800°F in the gas temperature has been found to correspond to only a small change of about 200°F in the fuel bed temperature.

For this reason a new electric furnace pyrometer has been devised of a high "sampling efficiency" and of great sensitivity and simplicity. This thesis comprises a discussion of the theory design and test of this type of furnace pyrometer which was installed on a 350 H.P. Stirling Boiler at ^{the} Armour Institute steam power plant.

GENERAL DESCRIPTION AND THEORY

In practically every furnace, the hot gases pass over the bridge wall before reaching the boiler tubes or the flues, as the case may be. The average temperature of the gases as they pass over the bridge wall is, therefore, the one that would indicate the combustion efficiency of the furnace.

Suppose now that a conducting, say metal, tube is passed through the setting above the full length of the bridge wall and water is allowed to flow continuously through this tube at a constant rate. Then the rise in the temperature of the water due to the effect of the hot gases on the tube is evidently an indication of the average temperature of the hot gases along the full length of the bridge wall.

The test pyrometer used on the Sterling Boiler consisted of 3/4" wrought iron pipe stretched across the bridge wall and supported by a 24" wall on one side and by about a 36" wall on the other side. It was connected to a city water main, and discharged into the sewer, the flow being regulated by means of a valve.

The design of such a pyrometer involves two distinct phases.

(1) The thickness, diameter, length and material of the tube must be such that the final water temperature for the highest furnace temperature to be measured

shall be safely below boiling point. The rise of the water temperature should be between 25 and 100°F. to be conveniently measured, and the heat absorbed by the pyrometer tube should be as small as possible, or only a fraction of a percent of the boiler rating. The coefficient of heat transmission should bear a definite constant relation to the temperatures measured.

(2) The thermal e.m.f., if thermo-couples are used, should be sufficient to make it possible to use a comparatively rugged millivoltmeter. If a recording pyrometer is desired, means must be found to measure something which can be recorded, e.g., resistance.

The problem then is both a mechanical and electrical one.

Analyzing the problem of heat transmission first, we have the relation;

(1) $US (t_g - t_w) = \text{Heat absorbed by tube,}$

and

(2) $60 WC (t_2 - t_1) = \text{Heat given up to water,}$

where

$U = \text{Coeff. of heat transmission} \quad \frac{\text{Btu.}}{\text{Hr.} \times \text{Sq. Ft.} \times ^\circ\text{F.}}$

$S = \text{Tube Surface, Sq. Ft.}$

$t_g = \text{Temperature of gases in furnace}$

$t_w = \text{Mean temper. of water in tubes}$

t_2 = Temper of water, hot end

t_1 = " " " , cold end

W = Water discharge, LBS./M I N

C = Specific heat of water = 1

Since there are practically no losses, we have,

$$(3) \quad US (t_g - t_w) = 60 W (t_2 - t_1)$$

For an average value of $U = 20$, as commonly used for boiler tubes, and for the pyrometer tube furnace temperature, etc. as used on the Stirling boiler, we have, $U = 20$,

$$S = \pi d L; d = 1" \text{ (O.D.)}; L = 9'3" = 9.25'$$

or

$$S = \frac{9.25\pi}{12} = 2.42 \text{ sq. ft.}$$

$$t_g = 2000^\circ\text{F.}$$

$$t_w = 100^\circ\text{F.}$$

$$W = 60 a v D; a = .533 \text{ sq. in.}$$

$$V = 1.5 \text{ ft/sec. } D = 62 \text{ \#/cu.ft.}$$

or

$$W = \frac{60 \times .533 \times 1.5 \times 62}{144} = 20.7 \text{ lbs/min}$$

Therefore, the rise in water temperature is,

$$T_2 - t_1 = \frac{US (t_g - t_w)}{60W} = \frac{20 \times 2.42 \times 1900}{60 \times 20.7} = 74^\circ\text{F.}$$

The water is, therefore, safely below boiling point for the case considered. If the furnace temperature is much higher than 2000°F. the water rise may be still kept down by increasing the flow. Thus, if the

velocity is increased from 1.5 to say 3 ft./sec. the temperature of the furnace could be in the neighborhood of 3900°F. for the same water temperature rise of 74°F.

It is also evident that the above water temperature rise is large enough for electrical measurement. However, if we analyze the assumed design for heat absorbed, we find that,

$$\begin{aligned}\text{Heat absorbed} &= US (t_g - t_w) = 20 \times 2.42 \times 1900 = \\ &= \frac{92,000 \text{ Btu/Hr}}{33,500} = \\ &= 2.75 \text{ Boiler Horse Power.}\end{aligned}$$

or

$100 \frac{2.75}{350} = .785\%$ Boiler rating which is unnecessarily too large.

By proper choice of the material and the dimensions of the pyrometer tube, the heat absorbed may be considerably reduced without appreciably affecting the water temperature rise or the sensitivity of the pyrometer. For, rewriting (3) we get,

$$\begin{aligned}U d_l (t_g - t_w) &= 3600 \pi v D (t_2 - t_1) = \\ &= 3600 \frac{\pi (Kd)^2}{4 \times 144} 62 v (t_2 - t_1)\end{aligned}$$

or

$$VL (t_g - t_w) = 387 k^2 d v (t_2 - t_1),$$

where \underline{K} is the ratio of inside diameter
outside diameter

(4) From the last equation we note that if \underline{U} is decreased we must only decrease either $\underline{K^2 d}$ or \underline{v} in proportion, to still retain the same water tempera-

ture rise, $t_2 - t_1$.

Now, sensitivity may be considered as the time it takes for a change in furnace temperature to be recorded by the pyrometer. For a given lag of heat transmission through the pyrometer tube, the time considered, must evidently depend upon the time it takes for the water to pass through the full length of the tube. Therefore, the greater the velocity of flow, the shorter this time is and the greater the sensitivity. Therefore, to reduce the heat absorbed without affecting either sensitivity or rise of water temperature, the proper method is to decrease the coefficient of heat transmission U , and the diameter, d , of the pyrometer tube or the expression, $K^2 d$ in equal proportion.

It may be remarked, in passing that for the pyrometer tube under discussion, the time it takes for a particle of water to move from the cold to the hot end is,

$$t = \frac{L}{v} = \frac{9.25}{1.5} = \underline{6.16 \text{ sec.}}$$

If a change of furnace temperature occurs at the hot end of the pyrometer tube the time it takes for the effect to be recorded is zero. The mean time for the recording of furnace temperature changes at any point of the tube must therefore, be,

$$\frac{t_a + 0}{2} = \underline{3.08 \text{ sec.}}$$

Hence the gratifying sensitivity of this type of furnace pyrometer.

Before redesigning the tube, let us rewrite equation 1 and 4 in terms of internal diameter d_i , of the tube, and thickness, $T=nd_i$. Thus,

$$(5) \quad d=d_i+T=d_i(1+n),$$

$$(1_a) \quad US(t_g-t_w)=V\pi dL(t_g-t_w)=U\pi d_i(1+n)L(t_g-t_w)=\text{Heat absorbed,}$$

$$(4_a) \quad UL(t_g-t_w)=387 \frac{d_i^2}{d} v(t_2-t_1)=387 \frac{d_i}{1+n} v(t_2-t_1)$$

Suppose, now, that the inside diameter, d_i , is reduced from $\frac{3}{4}$ " to $\frac{1}{4}$ ", and U is decreased in proportion, or to $1/3$ its original value. Then there will be no change in either sensitivity or water temperature rise, but there will be a large reduction in heat absorbed, since in eq. (1_a) reduced to $1/3$ their former value. The reduction is therefore to $1/9$ of the former heat absorbed, and we have,

$$\begin{aligned} \text{Heat absorbed} &= 1/9 (92,000) = \underline{10,200 \text{ Btu/hr}} = \frac{10,200}{33,500} = \\ &= \underline{.3 \text{ Boiler Horse Power}} \end{aligned}$$

The value of U can be reduced by increasing the thickness of the pyrometer tubes and by choosing a material which is a cross between a good heat conductor and an insulator. It is thought that alundum, the earthen material, which has lately come into use for protecting pyrometer thermocouples, is such a material, inasmuch as it certainly has a much smaller heat conductivity than metal, but still has not so much heat transmission as to be unsuited for pyrometry.

The experimental investigation of the furnace pyrometer under discussion was planned along the following lines:

THE UNIVERSITY OF CHICAGO

1911

TO THE PRESIDENT OF THE UNIVERSITY OF CHICAGO

FROM THE FACULTY OF THE UNIVERSITY OF CHICAGO

RESOLUTION

WHEREAS the Faculty of the University of Chicago
has the honor to receive from the President of the University of Chicago
a copy of the report of the Committee on the University of Chicago
which was appointed by the Board of Trustees of the University of Chicago
in the year 1908

and whereas the Faculty of the University of Chicago
has the honor to receive from the President of the University of Chicago
a copy of the report of the Committee on the University of Chicago
which was appointed by the Board of Trustees of the University of Chicago
in the year 1908
and whereas the Faculty of the University of Chicago
has the honor to receive from the President of the University of Chicago
a copy of the report of the Committee on the University of Chicago
which was appointed by the Board of Trustees of the University of Chicago
in the year 1908

Resolved that the Faculty of the University of Chicago
do hereby accept of the report of the Committee on the University of Chicago
which was appointed by the Board of Trustees of the University of Chicago
in the year 1908

ADOPTED

THE FACULTY OF THE UNIVERSITY OF CHICAGO
DOES HEREBY ACCEPT OF THE REPORT OF THE COMMITTEE ON THE UNIVERSITY OF CHICAGO
WHICH WAS APPOINTED BY THE BOARD OF TRUSTEES OF THE UNIVERSITY OF CHICAGO
IN THE YEAR 1908
AND WHEREAS the Faculty of the University of Chicago
has the honor to receive from the President of the University of Chicago
a copy of the report of the Committee on the University of Chicago
which was appointed by the Board of Trustees of the University of Chicago
in the year 1908
and whereas the Faculty of the University of Chicago
has the honor to receive from the President of the University of Chicago
a copy of the report of the Committee on the University of Chicago
which was appointed by the Board of Trustees of the University of Chicago
in the year 1908

IN WITNESS WHEREOF

THE FACULTY OF THE UNIVERSITY OF CHICAGO

(1) The relation between furnace temperature distribution and the furnace pyrometer was to be investigated for different temperature ranges. The coefficient of heat transmission, U , was to be found for different furnace temperatures, with the velocity of the water in the pyrometer tubes being kept constant. The effect, if any, of tooth or fused ash accumulations on the pyrometer tube on the coefficient of heat transmission, U was to be found; also, the variation, if any, of U , with the velocity of the water in the pyrometer tube.

(2) The relation between heat transmission, from a hot gas to water through a tube, and the thickness of the tube was to be sought. Seamless steel and alundum tubes were to be experimented with.

Because of the great time consuming nature of investigating furnace temperature distribution, all readings were taken only for a constant water velocity of about, 1.5 ft/sec. Preparations were made for part (2) of the test, but the electric furnace used could not produce a temperature of 2000° F. as was planned. It was calculated that it would be necessary to almost double the platinum ribbon winding of the furnace in order to consume the full 3KW. of the furnace rating, since the current was limited to 30 amperes. Various factors made this plan unattainable within the period available for the investigation, and the latter had to be postponed for a future time.

However, the method of analyzing the effect of tube thickness on the coefficient of heat transmission is given below, the derivations of the basic relations being given in the appendix.

Before taking this matter up, it is interesting to note what the effect according to eq. (4a) and (1a) would be if the thickness of tube were varied for a given internal diameter d_i . Thus, if the thickness were increased, and therefore also e^{1+n} , then according to

1. The first of these is the fact that the

the first of these is the fact that the

the first of these is the fact that the

the first of these is the fact that the

the first of these is the fact that the

the first of these is the fact that the

the first of these is the fact that the

the first of these is the fact that the

the first of these is the fact that the

the first of these is the fact that the

the first of these is the fact that the

the first of these is the fact that the

the first of these is the fact that the

the first of these is the fact that the

the first of these is the fact that the

the first of these is the fact that the

the first of these is the fact that the

the first of these is the fact that the

the first of these is the fact that the

the first of these is the fact that the

the first of these is the fact that the

the first of these is the fact that the

the first of these is the fact that the

the first of these is the fact that the

the first of these is the fact that the

the first of these is the fact that the

the first of these is the fact that the

the first of these is the fact that the

eq. (1a), V would have to be proportionately decreased in order that the heat absorbed should not increase also. Increasing of thickness would decrease U but in all probably much less than in proportion to $l+n$. Therefore, for a given material with a fixed internal diameter, increase of thickness would probably also increase the heat absorbed by the tube. If the changes of $l+n$ and U were universally proportional to each other, then according to eq. (4a) the water temperature rise would not be affected thereby. But neither would the heat absorbed be decreased. Therefore, at the best there would be no gain. In fact since, in all probability, the coefficient, U would be decreased but slightly in comparison with the effect of increase of thickness upon the increase of $l+n$, the net result would be an increase in water temperature rise, t_2-t_1 . Although the latter is in itself desirable, it is not so at the expense of increase in heat absorbed. However, just what relation does increase in thickness bear to decrease in V is something to be found yet.

It is shown in the appendix that if, t_g =mean temperature of the gas, t_{mo} =mean temperature of tube, outside

t_{mi} = " " " " , inside

t_m = " " " " , at any thickness, l , from inside surface.

t_1 =temperature of water, cold end

t_2 = " " " " , hot "

t = " " " " , at distance, L , from cold end.

d_x =diameter of any point inside the metal

V_1 =coefficient of heat transmission, from gas to metal

V_2 = " " " " " metal to liquid

C =Metal conductivity,

that the fact that as much heat is transmitted from the gas to the

metal as through the metal as well as from the metal to the water can be expressed by the following three equations:

$$(6) V \pi d (t_g - t_{m0}) = C \pi d_x \frac{\partial t_m}{\partial d_x}$$

$$(7) C \pi d_x \frac{\partial t_m}{\partial d_x} = V_2 \pi k d (t_{mi} - t)$$

$$(8) V_2 \pi k d (t_{mi} - t) = \frac{w r k^2 d^2}{4} v \frac{\partial t}{\partial l}$$

Since the heat transmitted through any given cylindrical layer of metal must be the same as that passing through any other layer, this heat must be independent of the cylindrical layer diameter, d_x , and must be a function of L only; i. e.,

$$(9) C \pi d_x \frac{\partial t_m}{\partial d_x} = f(L)$$

With the help of the last equation, the preceding three can be modified, as shown in the appendix, to the following forms:

$$(6a) A_1 (t_g - t_{m0}) = A_2 (t_{m0} - t_{mi})$$

$$(7a) A_2 (t_{m0} - t_{mi}) = A_3 (t_{mi} - t)$$

$$(8a) A_3 (t_{mi} - t) = f(L)$$

where,

$$A_1 = V \pi d$$

$$A_2 = \log_e \frac{1}{k}$$

$$A_3 = V_2 \pi k d$$

$$f(L) = \frac{w r k^2 d^2}{4} v \frac{\partial t}{\partial L}$$

If for direct comparison between the gas temperature, t_g , and the water temperature, t , the common form for the heat transmission equation, were used, we should have,

$$(10) V \pi d (t_g - t) = f(L), \text{ or}$$

$$(10a) A (t_g - t) = f(L)$$

where,

... ..

... ..

$$\begin{aligned} \frac{d}{dt} \left(\frac{1}{2} m v^2 \right) &= \frac{d}{dt} \left(\frac{1}{2} m v_x^2 + \frac{1}{2} m v_y^2 + \frac{1}{2} m v_z^2 \right) \\ &= m v_x \frac{dv_x}{dt} + m v_y \frac{dv_y}{dt} + m v_z \frac{dv_z}{dt} \\ &= m v_x a_x + m v_y a_y + m v_z a_z \end{aligned}$$

... ..

... ..

$$\begin{aligned} \frac{d}{dt} \left(\frac{1}{2} m v^2 \right) &= \frac{d}{dt} \left(\frac{1}{2} m v_x^2 + \frac{1}{2} m v_y^2 + \frac{1}{2} m v_z^2 \right) \\ &= m v_x \frac{dv_x}{dt} + m v_y \frac{dv_y}{dt} + m v_z \frac{dv_z}{dt} \end{aligned}$$

... ..

$$\begin{aligned} \frac{d}{dt} \left(\frac{1}{2} m v^2 \right) &= \frac{d}{dt} \left(\frac{1}{2} m v_x^2 + \frac{1}{2} m v_y^2 + \frac{1}{2} m v_z^2 \right) \\ &= m v_x \frac{dv_x}{dt} + m v_y \frac{dv_y}{dt} + m v_z \frac{dv_z}{dt} \end{aligned}$$

... ..

$$\begin{aligned} \frac{d}{dt} \left(\frac{1}{2} m v^2 \right) &= \frac{d}{dt} \left(\frac{1}{2} m v_x^2 + \frac{1}{2} m v_y^2 + \frac{1}{2} m v_z^2 \right) \\ &= m v_x \frac{dv_x}{dt} + m v_y \frac{dv_y}{dt} + m v_z \frac{dv_z}{dt} \end{aligned}$$

$$\frac{d}{dt} \left(\frac{1}{2} m v^2 \right) = \dots$$

... ..

... ..

$$\begin{aligned} \frac{d}{dt} \left(\frac{1}{2} m v^2 \right) &= \frac{d}{dt} \left(\frac{1}{2} m v_x^2 + \frac{1}{2} m v_y^2 + \frac{1}{2} m v_z^2 \right) \\ &= m v_x \frac{dv_x}{dt} + m v_y \frac{dv_y}{dt} + m v_z \frac{dv_z}{dt} \end{aligned}$$

... ..

$$A = V_A d$$

The relation between this "resultant" coefficient, \underline{V} , and the "component" coefficients,

V_1, V_2, C , is shown to be,

$$(11) \quad \frac{1}{A} = \frac{1}{A_1} + \frac{1}{A_2} + \frac{1}{A_3},$$

or similar to the expression for electrical resistances in series,.

Since V, V_1, V_2 , and C increase with "heat conductance", their reciprocals, and therefore also, $\frac{1}{A}, \frac{1}{A_1}, \frac{1}{A_2}, \frac{1}{A_3}$ represent what may be called "heat resistances". There is thus an analogy between the expressions for electrical resistances and for heat resistances in series, which is rather striking.

Rewriting equation (11) with proper substitutions, we get,

$$(12) \quad \frac{1}{V_A d} = \frac{1}{V_1 r d} + \frac{\log_e K}{C r} + \frac{1}{V_2 r k d}$$

or

$$(12a) \quad \frac{1}{V} = \frac{1}{V_1} + \frac{d \log_e K}{C} + \frac{1}{kV}$$

Since,

$$d_i = kd,$$

the last equation may also be written as,

$$(13) \quad \frac{1}{V} = \frac{1}{V_1} + \frac{d_i \log_e K}{KC} + \frac{1}{kV}$$

from which it is apparent that if, for a constant inside diameter, d_1 , of pyrometer tube, the thickness of the latter and therefore \underline{K} be varied, different values of \underline{V} will be obtained. If now three such thicknesses were investigated, we should get three equations, ^{with three} unknowns, V_1, V_2 and C , and these equations would be independent of each other. By solving these equations, the values of V_1, V_2 , and C would be found as separate coefficients rather than their resultant value, \underline{V} , which is the coefficient usually measured.

$$F \cdot V = \dots$$

the $\frac{1}{V}$ of the "normal" state, and the $\frac{1}{V}$ of the

"normal" state, and the $\frac{1}{V}$ of the

$$\frac{1}{V} = \frac{1}{V_1} + \frac{1}{V_2} + \dots$$

$$\frac{1}{V} = \frac{1}{V_1} + \frac{1}{V_2} + \dots$$

the $\frac{1}{V}$ of the "normal" state, and the $\frac{1}{V}$ of the

$$\frac{1}{V} = \frac{1}{V_1} + \frac{1}{V_2} + \dots$$

$$\frac{1}{V} = \frac{1}{V_1} + \frac{1}{V_2} + \dots$$

$$\frac{1}{V} = \frac{1}{V_1} + \frac{1}{V_2} + \dots$$

the $\frac{1}{V}$ of the "normal" state, and the $\frac{1}{V}$ of the

the $\frac{1}{V}$ of the "normal" state, and the $\frac{1}{V}$ of the

the $\frac{1}{V}$ of the "normal" state, and the $\frac{1}{V}$ of the

$$\frac{1}{V} = \frac{1}{V_1} + \frac{1}{V_2} + \dots$$

$$\frac{1}{V} = \frac{1}{V_1} + \frac{1}{V_2} + \dots$$

the

$$\frac{1}{V} = \frac{1}{V_1} + \frac{1}{V_2} + \dots$$

the

$$\frac{1}{V} = \frac{1}{V_1} + \frac{1}{V_2} + \dots$$

the $\frac{1}{V}$ of the "normal" state, and the $\frac{1}{V}$ of the

$$\frac{1}{V} = \frac{1}{V_1} + \frac{1}{V_2} + \dots$$

the $\frac{1}{V}$ of the "normal" state, and the $\frac{1}{V}$ of the

the $\frac{1}{V}$ of the "normal" state, and the $\frac{1}{V}$ of the

$$\frac{1}{V} = \frac{1}{V_1} + \frac{1}{V_2} + \dots$$

the $\frac{1}{V}$ of the "normal" state, and the $\frac{1}{V}$ of the

the $\frac{1}{V}$ of the "normal" state, and the $\frac{1}{V}$ of the

$$\frac{1}{V} = \frac{1}{V_1} + \frac{1}{V_2} + \dots$$

the $\frac{1}{V}$ of the "normal" state, and the $\frac{1}{V}$ of the

$$\frac{1}{V} = \frac{1}{V_1} + \frac{1}{V_2} + \dots$$

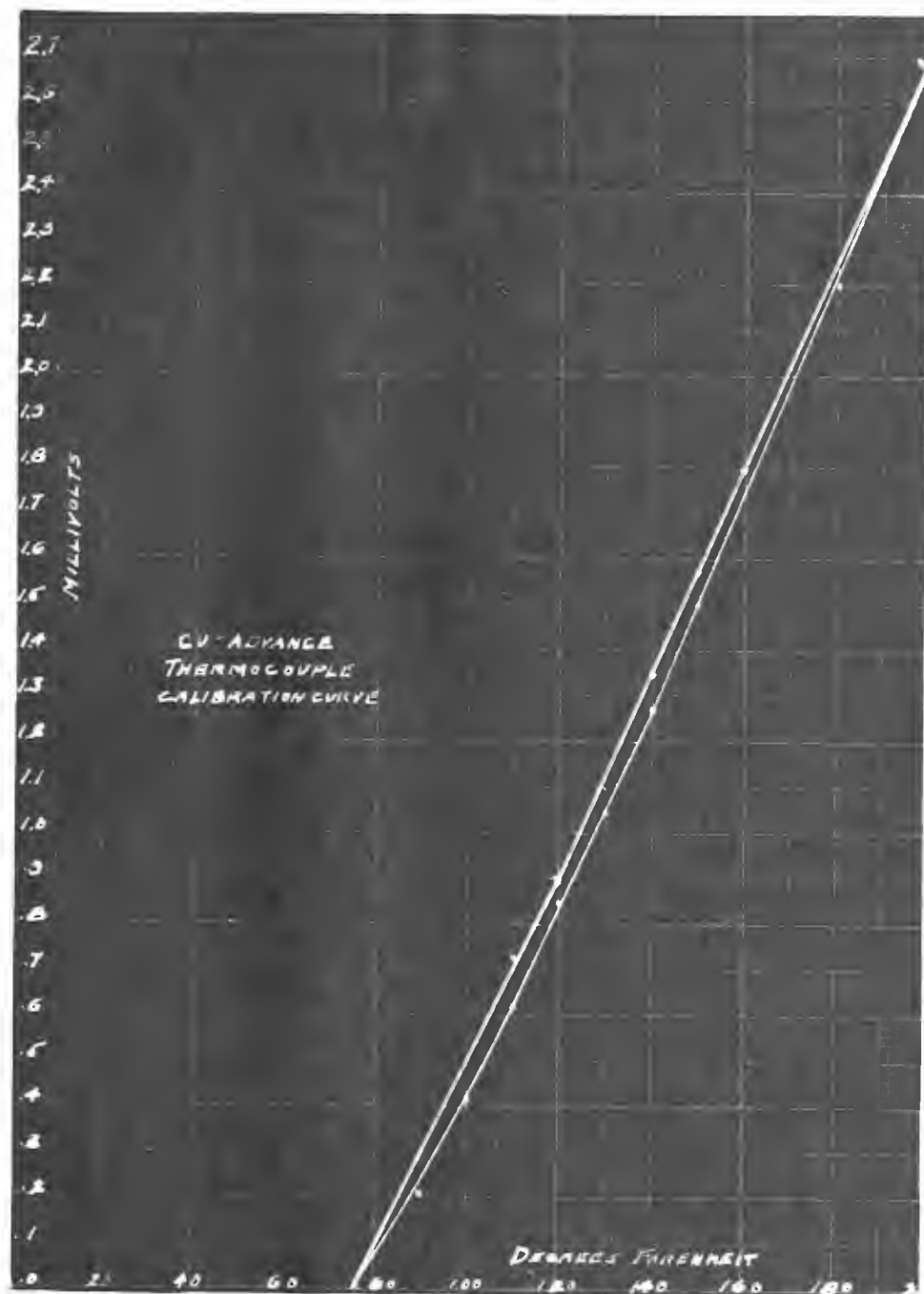
Then the value of V could be calculated , from eq. (13) for various thicknesses of tube, without the necessity of investigating each case experimentally. Also, knowing the effect of metal thickness upon the resultant coefficient of heat transmission, V , design problems involving the thickness of pyrometer tubes could be analyzed and solved rationally.

Beside the mechanical problem of heat transmission involved in the electric furnace pyrometer design, there is the electrical problem of measuring and recording water temperature rise electrically.

Figure 5.

For indicating purposes, copper-advance thermocouples may be used. Their calibration curve is shown in Fig. 1.

Figure 1.



non finito tingit etiam non

Thalia celebrata in ovine m. l. d. d. d.

.f. singl.

To increase the thermal e. m. f. a number of them may be included in the same temperature plug and connected at their cold ends in series. Because of the small room occupied by these thin thermocouples it would be no difficulty of placing as many as 10 to 20 of them in the same plug, and the temperature of water could be measured within. If now, one such plug is screwed into the cold end of the pyrometer tube and another one into the hot end of this tube, the difference between the two thermal e. m. f.'s. will be proportional to the difference of temperature between the hot and cold ends of the pyrometer tubes. This is evident if it is noted that the cold ends of the two thermocouples are at the same temperature, too. Then the emf's generated by the thermocouples are,

$$(14) \quad L_2 = K (t_2 - t_0)$$

$$(15) \quad L_1 = K (t_1 - t_0)$$

If now the difference between these two e. m. f.'s is measured by means of a differential millivoltmeter, the reading of the latter in millivolts will be proportional to the temperature difference, $t_2 - t_1$.

Thus,

$$(16) \quad L_2 - L_1 = K (t_2 - t_1)$$

The differential millivoltmeter may be calibrated to read, the difference between furnace and room temperature; or it may be calibrated to read o/o excess air directly.

Thus, for the first case, we combine equations (4a) and (16), and we get,

$$(17) \quad t_g - t_w = \frac{387 \text{ div } (t_2 - t_1)}{(1+n) \sqrt{L}} = \frac{387 \text{ div}}{K(1+n) \sqrt{L}} (L_2 - L_1) = K (L_2 - L_1)$$

Since the difference between the mean water temperature, t_w , in the pyrometer tube and the room temperature, t_0 , is small as compared with the furnace temperature, t_g , the above expression shows ~~the difference~~

that the millivoltmeter measures the difference between furnace and room temperatures directly.

For the second case, we note that the rise in temperature of the gases in the furnace above room temperature may be expressed by,

$$(18) \quad t_g - t_a = \frac{fH}{(W+1)C_p}$$

where,

H = Btu/# coal

W = # air /# coal

C_p = specific heat of air, at constant pressure

f = correction factor for radiation, incomplete combustion, etc.

Now, it is an accepted fact that for all coals, about 7.5 lbs. of air are required for each 10,000 Btu in the coal, Therefore, the theoretical air requirements, W_o , for H Btu or per lb. of coal is,

$$(19) \quad W_o = \frac{7.5 H}{10,000}$$

If n times the theoretical requirements of air is used, then,

$$(20) \quad W = nW_o = \frac{7.5nH}{10,000}$$

and the temperature equation (18) may be rewritten as,

$$(21) \quad t_g - t_a = \frac{fH}{\left(\frac{7.5nH}{10,000} + 1 \right) C_p} = \frac{f}{\left(\frac{7.5n}{10,000} + \frac{1}{H} \right) C_p}$$

Since, the expression $\frac{1}{H}$ is much smaller than $\frac{7.5n}{10,000}$, we may replace the former with the average value corresponding to $H = 12,500$ Btu./#, and we get,

$$(21a) \quad t_g - t_a = \frac{f}{\left(\frac{7.5n}{10,000} + 0.00008 \right) C_p}$$

For any given furnace, the correction factor f , which depends mainly upon the direct radiation from the fire to the boiler, is a fixed

THEORY OF THE EARTH AND ITS HISTORY

CHAPTER I. THE EARTH AND ITS HISTORY

1. THE EARTH AND ITS HISTORY

2. THE EARTH AND ITS HISTORY

3. THE EARTH AND ITS HISTORY

4. THE EARTH AND ITS HISTORY

5. THE EARTH AND ITS HISTORY

6. THE EARTH AND ITS HISTORY

7. THE EARTH AND ITS HISTORY

8. THE EARTH AND ITS HISTORY

9. THE EARTH AND ITS HISTORY

10. THE EARTH AND ITS HISTORY

11. THE EARTH AND ITS HISTORY

12. THE EARTH AND ITS HISTORY

13. THE EARTH AND ITS HISTORY

14. THE EARTH AND ITS HISTORY

15. THE EARTH AND ITS HISTORY

16. THE EARTH AND ITS HISTORY

17. THE EARTH AND ITS HISTORY

18. THE EARTH AND ITS HISTORY

19. THE EARTH AND ITS HISTORY

20. THE EARTH AND ITS HISTORY

21. THE EARTH AND ITS HISTORY

characteristic. Therefore, when f or rather the ratio of $\frac{f}{C_p}$ is once determined for a given boiler setting, the relation between furnace temperature difference, $t_g - t_a$, and o/o air, n , becomes fixed and definite, regardless what the nature of coal or the flue gas analysis may be.

Thus, for $f = .80$, $C_p = .24$, and theoretical air requirements or $n = 1$, we get,

$$t_g - t_a = \frac{.80}{(.00075 + .00008) .24} = 4000^\circ \text{ F}$$

For the same conditions and 200% air, or $n = 2$, we get,

$$t_g - t_a = \frac{.80}{(.00150 + .00008) .24} = 2100^\circ \text{ F}$$

which justifies the statement previously made that the furnace pyrometer indication is approximately inversely proportional to the o/o air used for combustion. The more exact relation is given by equation (21a). It is to be noted also, that if in the case of theoretical air requirements, the assumption of 12,000 Btu/# coal has an error of say 10%, then since .00008 is about 10% of .00075, a 10% error in the former results in only 10% of 10% or 1% in the sum of $.00075 + .00008 = .00083$. For 100% excess air this error is reduced to $\frac{1}{2}\%$, etc. Since the usual condition is 100% or more excess air, the approximation of $\frac{1}{H} = .00008$ is within permissible limits of error, and equation (21a) is justified.

Evidently then by combining equations (17) and (21a), we can get a direct relation between millivoltmeter readings, $e_2 - e_1$, and % air, n , used in the furnace. Thus we have,

$$(22) \quad t_g - t_w = \frac{387 d_i v (e_2 - e_1)}{K (1+n) L} = t_g - t_a = \frac{f}{\left(\frac{7.5n}{10,000} + .00008 \right) C_p}$$

or

... ..
... ..
... ..
... ..
... ..

... ..
... ..

... ..

... ..

... ..

... ..

... ..

... ..

... ..

... ..

... ..

... ..

... ..

... ..

... ..

... ..

... ..

... ..

... ..

... ..

... ..

$$(23) \quad n = \left[\frac{k_f (1+n) \sqrt{L}}{387 d_i \sqrt{C_p} (e_2 - e_1)} - .00008 \right] \frac{10,000}{7.5} =$$

$$= \frac{3.45 k_f (1+n) \sqrt{L}}{d_i \sqrt{C_p}} \frac{1}{e_2 - e_1} - .107 = \frac{k_2}{e_2 - e_1} - .107$$

where,

$$k_2 = \frac{3.45 K_f (1+n) \sqrt{L}}{d_i \sqrt{C_p}}$$

By means of the last equation, the millivoltmeter may evidently be calibrated ^{to read % air in furnace} directly.

If the furnace temperature difference is to be recorder, the thermocouples are replaced by resistance coils of appreciable resistance temperature coefficient. Very thin enameled copper wire is best for the low temperatures (below 200° F) encountered in the water of the pyrometer tube. Thus, since,

$$(24) \quad R_1 = R_0 [1 + a (t_1 - 32)]$$

$$(25) \quad R_2 = R_0 [1 + a (t_2 - 32)]$$

where R_0 = resistance of the wire at 32°F we have,

$$(26) \quad R_2 - R_1 = R_0 a (t_2 - t_1)$$

Therefore, the water temperature rise may be calculated by measuring the difference of resistance between two copper coils placed at the hot and cold ends of the pyrometer tube, respectively. The relation between the resistance difference, $R_2 - R_1$, and the furnace temperature difference is the same as that given by eq. (17) for thermocouples, if K is replaced by $R_0 a$. The same holds true for the % air relation, as given by eq. (23).

To measure the difference of resistance, $R_2 - R_1$, automatically, the differential galvanometer method is used. The galvanometer will read zero when sufficient balancing resistance is added in series with the smaller resistance, R_1 , to balance the larger resistance R_2 , i. e.,

1990

1. The first part of the document is a list of names and titles, including "The Hon. Mr. Justice" and "The Hon. Mr. Justice".

100

—

1. The first group of people who are interested in the study of the history of the United States are the people who are interested in the history of the United States.

10. $\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$

Journal of Management Education 30(6)

when the voltage across the first two resistances is equal to that across the last resistance. When due to change in temperature, the decrease or increase of resistances unbalances the voltages, the galvanometer will deflect in either direction depending upon the direction of unbalance.

If a galvanometer relay is used, similar ~~r~~ to the one used for flow measurement by the Sargen Steam Meter Co., then the deflection of the galvanometer may be caused to act like an automatic switch closing the field circuit of a series motor of the Universal type, and the motor will rotate in a direction corresponding to that of the galvanometer deflection. The motor may be made to move a rheostat handle and thus vary the balancing resistance $R = R_2 - R_1$ until the galvanometer returns to its zero position, the field of the motor is automatically opened by the galvanometer relay, and the motor is stopped.

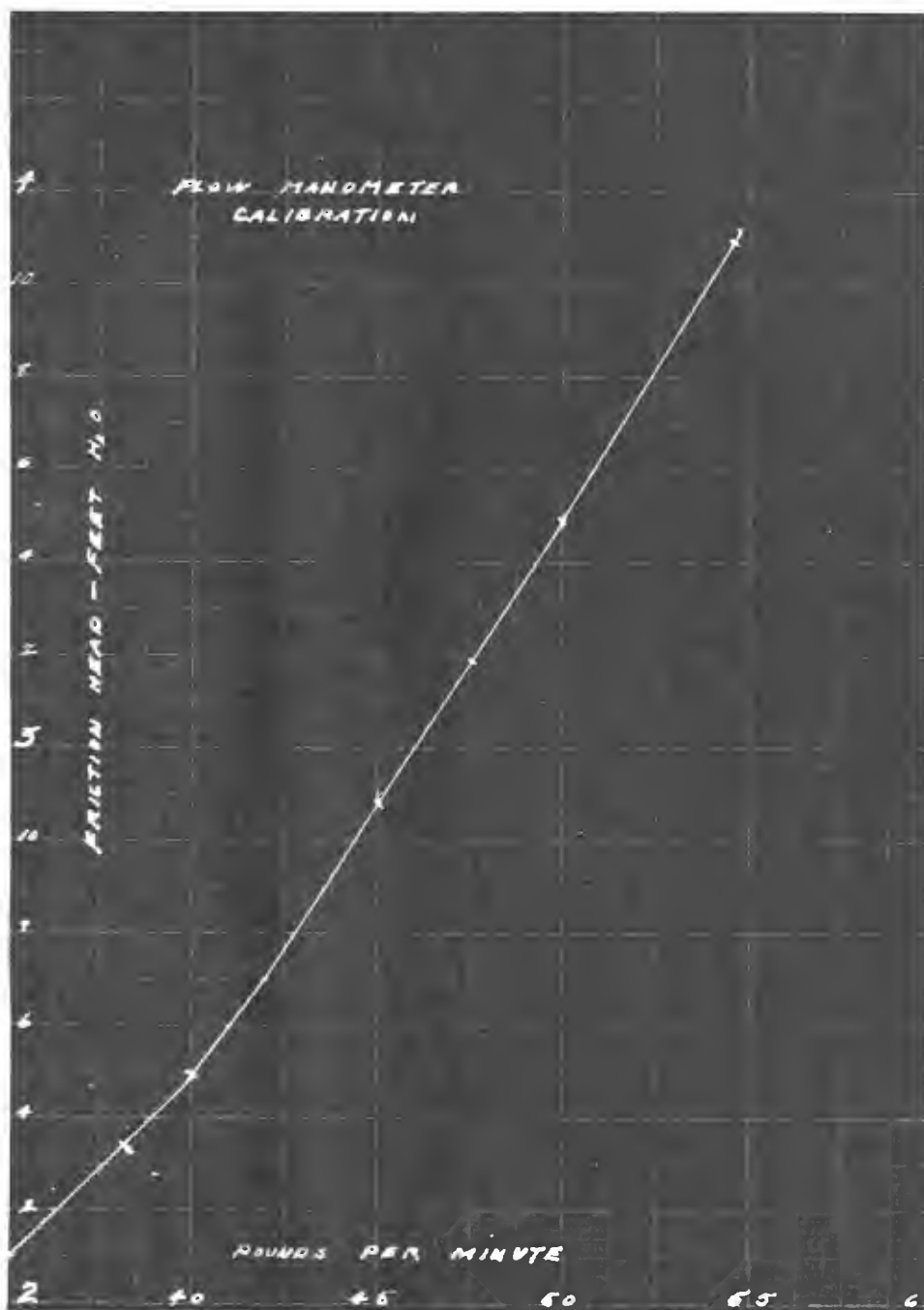
The balancing resistance $R = R_2 - R_1$ may be calibrated to read directly either furnace temperature difference, $t_g - t_a$, or % excess air, $n-1$, as may be desired. The motor may be made to move a graphic pen as well as an indicating pointer, and thus the pyrometer may be made recording.

FURNACE PYROMETER CALIBRATION

The pyrometer described was tested on a 350 H. P. Sterling ~~bit~~ boiler at the Armour Institute. The water was supplied by a $\frac{3}{4}$ " pipe line at city water pressure, the flow being regulated by a ~~be~~ valve. A monometer at the cold end of the pyrometer tube indicated the pressure of the flowing water at the beginning of the tube, and when at the hot end, the water was allowed to discharge freely into the ~~sewer~~ sewer at atmospheric pressure without any restricting valves, the monometer measured directly the friction pressure drop through the pyrometer tube. By actually weighing the water discharge, the

monometer may be calibrated to read lbs. of water per minute, directly. The monometer calibration curve, is shown in Fig. 2, below.

Figure 2.



... ..
... ..
... ..

41

By setting the valve until the monometer indicated corresponded to the desired flow, the latter could be maintained constant during each run.

Specially made temperature cups were screwed into ~~Y~~ Y fittings, once at the cold and another at the hot end of the pyrometer tube. These cups were partially filled with oil, and calibrated mercury thermometers were immersed into this oil. These thermometers gave the cold and hot end temperatures of the water flowing through the pyrometer tubes.

For measuring the furnace temperatures at the different points of the bridge wall, a thermocouple twelve feet long was obtained and marked every foot of its length. Also a small fire door between the bridge wall and the first row of boiler tubes was opened and an asbestos board with an opening on its bottom was fitted into the door cavity. The ~~ent~~ thermocouple could then be moved in and out the furnace through the opening of the asbestos board, without the objection of letting a lot of cold air into the furnace.

The thermocouple was connected to a Leeds & Northrop potentiometer type of millivoltmeter, the thermal e. m. f. being ~~being~~ balanced against the voltage drop across a variable calibrated resistance, produced by the e. m. f. of a standard cell. When the voltages were balanced, the thermal e. m. f. was disconnected, and the drop across the variable resistance was measured by the millivoltmeter. In that way, the error due to the voltage drops across the connecting wires were avoided.

The test consisted of adjusting the flow to a predetermined constant value by means of the valve and the monometer; of inserting the thermocouple to the last marked foot, and taking the temperature reading by means of the millivoltmeter; and finally, of reading the two mercury thermometers in the cold and hot end temperature cups.

The thermocouple would then be moved out to next foot mark, and the readings would be repeated. This was done for eight different foot marks, corresponding to almost every foot along the bridge wall.

A series of such tests were made on different days in order to cover as large a range of furnace temperature as possible.

A preliminary calibration test of the thermocouple was made in an electric furnace against a standard platinum thermocouple.

RESULTS AND CALCULATIONS

The calibration curve of the 12 foot thermocouple is shown in Figure 3. As shown by the curve, the calibration was made up to 2200° F.

FIGURE 3.

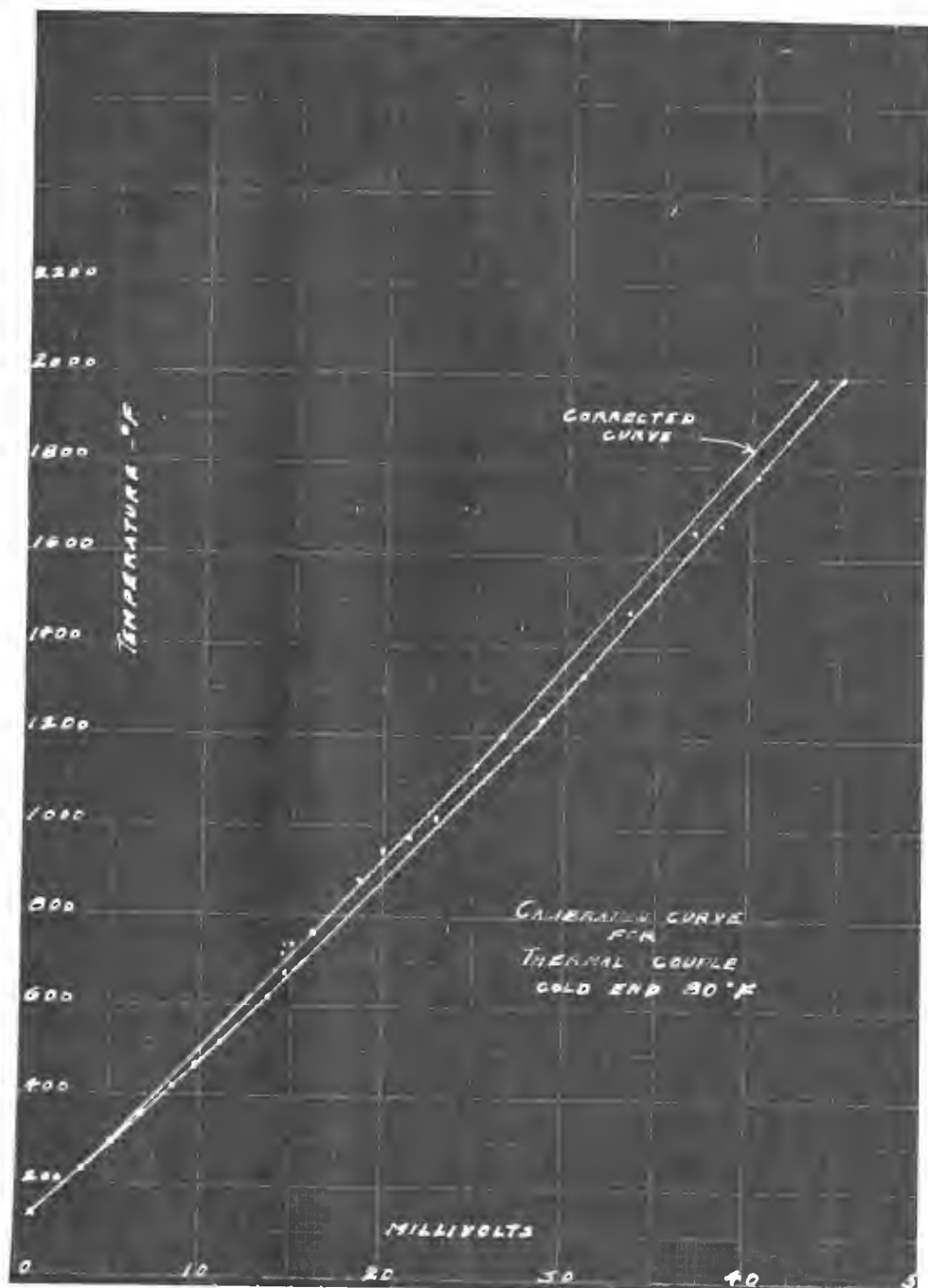


FIGURE 8.

Table 1 gives a sample of data taken for the furnace temperature distribution and heat transmission tests. From the millivoltmeter readings and the thermocouple calibration curve, the furnace temperatures were figured out at different points of the bridge wall.

of the other side of the mountain to the other side of the mountain

to the other side of the mountain to the other side of the mountain

to the other side of the mountain to the other side of the mountain

to the other side of the mountain to the other side of the mountain

TABLE 1.

SAMPLE DATA SHEET					
Point	MILLIVOLTS	Freeze Temp.	Cold and Temp.	Hot and Temp.	Temp difference
2	26.7	1210	44	114	70
3	39.1	1775	"	108.5	64.5
4	47.4	2160	"	113	69
5	41.7	1900	"	113	69
6	41	1865	"	115	71
7	38	1725	"	113	69
8	39.4	1790	"	113	69
9	41	1865	"	113	69

• J. 11111

Because of the variation of average furnace temperature during any one test, it was necessary to take the readings for the conditions as found and then tabulate them according to water temperature rises produced. Thus all readings corresponding to within $2\frac{1}{2}^{\circ}$ F on either side of say 400 F rise were tabulated together, and the furnace temperatures for the different points along the bridge wall for this average condition were thus available for comparison. Naturally, the tables for some such water temperature rises were more complete than for others, and special efforts were then made to secure the readings at the points and for the water temperatures for which one was short of data. The highest water temperature rises investigated were around the 900 F point.

A sample of such tabulated data as well as the averages of the furnace and water temperatures is given in Table 2. The latter also includes the calculated U for the particular furnace temperature difference under consideration.

TABLE 2.

1 2 3 4 5 6 7 8 9

T d T d T d T d T d T d T d T d

1310 67 1360 63 1440 66 1776 64.5 1700 64.5 1845 66.5 1815 64 1015 66 1790 63.5
 1325 64.5 1325 67 1570 66 1625 64.5 1685 67 1690 66.5 1810 66 1805 67 1795 64
 1620 62.5 1700 65.5 1735 63 1700 63 1650 65.5 1870 64 1765 67
 1720 67 1715 64.5 1805 65 1700 65 1740 66.5
 1304 65.75 1342 66 1605 63.5
 1593 65.6 1702 64.8 1710 64.75 1772 66.2 1792 64.8 1825 65.5 1797 66.3

Average T = 1630
 " d = 65.11
 " U = 22.45

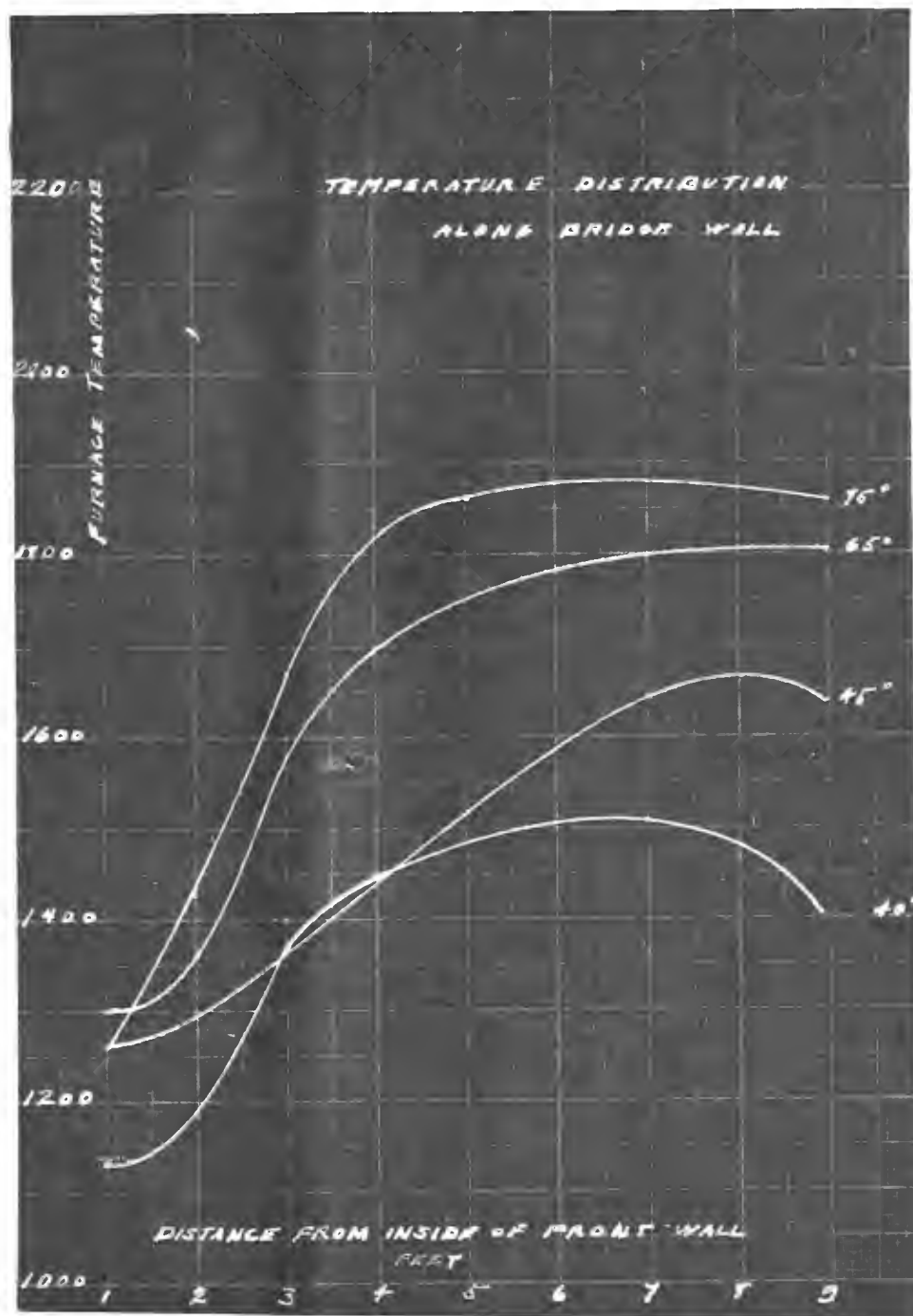
.2 HIGAL

It will be noted that for any given bridge wall point of this table the furnace temperature varies as much as 5% above the average temperature at this point. This indicates the variation of the temperature distribution along the bridge wall with time. If the variations at all points along the bridge wall were all in the same direction or non compensating, there would be a maximum possible, sampling error of 5%. Ordinarily there would be some compensation, so that the variation of the relation between the average furnace temperature and the average water temperature rise would be less than 5%. However, ~~as~~ to play safe, we may state that as efficient as about 10' of tube along the bridge wall may be for sampling purposes as compared with that of point sampling, ~~for~~ there is still a maximum possible error of 5% due to the variation of bridge wall temperature distribution.

It may now be in order to remark that the pyrometer tube ~~to~~ was slightly covered with sooth or slag, most of which was usually carried away by the moving gases. Several attempts were made to note the variation of the results, if the materials on the pyrometer tube were scraped off. It was found that there was about 1% increase in conductivity, when the tubes were thus treated. Considering the 5% possible error in the sampling efficiency of the tube, it is evident that the effect of sooth accumulation outside the tube is negligible.

The average temperature distribution curves along the bridge wall for several water temperature rises are plotted in Fig. 4 below.

FIGURE 4.



-CS-

.4 ENUGIM

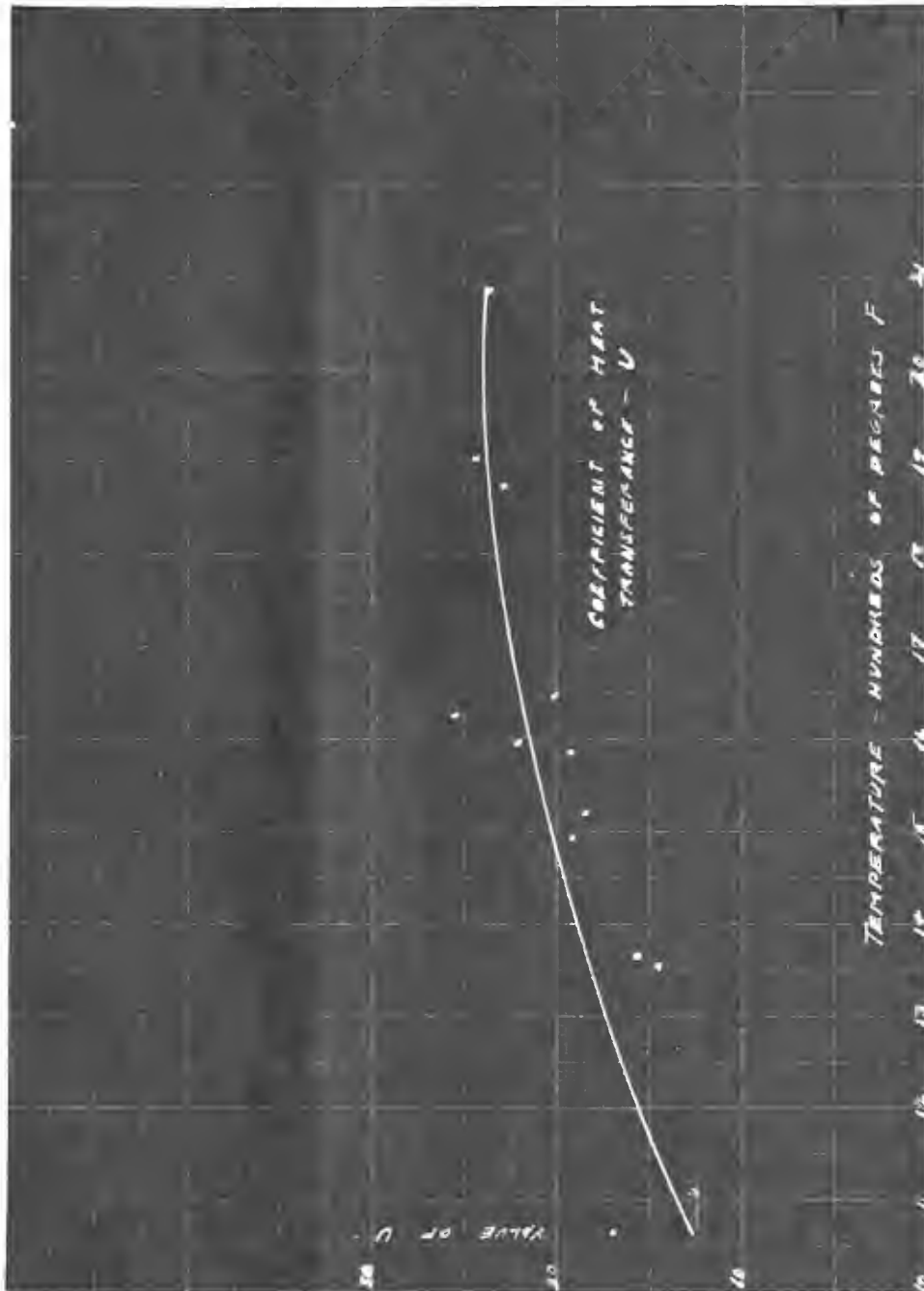
Figure 5 gives the \bar{U} - curve or the values of \bar{U} calculated for different furnace temperature differences, from the tables given in the appendix and similar to table 2.

From the curve values of \bar{U} could be found for any furnace temperature differences, $t_g - t_a$, and used for calibrating the indicating or recording pyrometer to read furnace temperature differences directly.

After a comparison is made between these values of U and those between these ~~value~~ that will be obtained from the heat transmission test using an electric furnace, it is hoped that a rational relation between U and overall temperature difference will be evolved.

[illegible]

FIGURE 5.



110 11 11

1	2	3	4	5	6	7	8	9
T	d	T	d	T	d	T	d	T

1700 89 1980 91 2160 91 2120 825 2155 2225 2035 885
2060 92

Average T = 2085
 " d = 31.74
 " U = 23.8

1	1	2	3	4	5	6	7	8	9
T	d	T	d	T	d	T	d	T	d
535 26	1025 27			1175 26		1245 26			
	1125 27			1270 26					

Average T: 1113
 " d: 26.21"
 " U: 73.23

1	2	3	4	5	6	7	8	9	10
T	T	T	T	T	T	T	T	T	T
d	d	d	d	d	d	d	d	d	d
1045.34									
1350.33	1618.37	1840.37							
1446.35	1435.38	1500.37							

Average T = 1354
 " d = 36.66
 " U = 14.57

1 2 3 4 5 6 7 8 9 10
 T d T d T d T d T d T d T d T d
 1105 38 1175 38 1400 38
 1130 405

GC 3961 14 5151 74 0051
 GC 3961 1515 39

Average T: 1365
 " d 3966
 " U 1504

	1	2	3	4	5	6	7	8	9
T	d	T	d	T	d	T	d	T	d
1330	44	1450	46	1655	-	1330	44	1670	47
1140	47.5	1410	48.5			1670	47	1815	48
						1335	45	1690	48.5
						1425	45		

Average T: 1495
 " d: 46.1
 " V: 10.05

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420	421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	444	445	446	447	448	449	450	451	452	453	454	455	456	457	458	459	460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480	481	482	483	484	485	486	487	488	489	490	491	492	493	494	495	496	497	498	499	500	501	502	503	504	505	506	507	508	509	510	511	512	513	514	515	516	517	518	519	520	521	522	523	524	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543	544	545	546	547	548	549	550	551	552	553	554	555	556	557	558	559	560	561	562	563	564	565	566	567	568	569	570	571	572	573	574	575	576	577	578	579	580	581	582	583	584	585	586	587	588	589	590	591	592	593	594	595	596	597	598	599	600	601	602	603	604	605	606	607	608	609	610	611	612	613	614	615	616	617	618	619	620	621	622	623	624	625	626	627	628	629	630	631	632	633	634	635	636	637	638	639	640	641	642	643	644	645	646	647	648	649	650	651	652	653	654	655	656	657	658	659	660	661	662	663	664	665	666	667	668	669	670	671	672	673	674	675	676	677	678	679	680	681	682	683	684	685	686	687	688	689	690	691	692	693	694	695	696	697	698	699	700	701	702	703	704	705	706	707	708	709	710	711	712	713	714	715	716	717	718	719	720	721	722	723	724	725	726	727	728	729	730	731	732	733	734	735	736	737	738	739	740	741	742	743	744	745	746	747	748	749	750	751	752	753	754	755	756	757	758	759	760	761	762	763	764	765	766	767	768	769	770	771	772	773	774	775	776	777	778	779	780	781	782	783	784	785	786	787	788	789	790	791	792	793	794	795	796	797	798	799	800	801	802	803	804	805	806	807	808	809	810	811	812	813	814	815	816	817	818	819	820	821	822	823	824	825	826	827	828	829	830	831	832	833	834	835	836	837	838	839	840	841	842	843	844	845	846	847	848	849	850	851	852	853	854	855	856	857	858	859	860	861	862	863	864	865	866	867	868	869	870	871	872	873	874	875	876	877	878	879	880	881	882	883	884	885	886	887	888	889	890	891	892	893	894	895	896	897	898	899	900	901	902	903	904	905	906	907	908	909	910	911	912	913	914	915	916	917	918	919	920	921	922	923	924	925	926	927	928	929	930	931	932	933	934	935	936	937	938	939	940	941	942	943	944	945	946	947	948	949	950	951	952	953	954	955	956	957	958	959	960	961	962	963	964	965	966	967	968	969	970	971	972	973	974	975	976	977	978	979	980	981	982	983	984	985	986	987	988	989	990	991	992	993	994	995	996	997	998	999	1000	1001	1002	1003	1004	1005	1006	1007	1008	1009	1010	1011	1012	1013	1014	1015	1016	1017	1018	1019	1020	1021	1022	1023	1024	1025	1026	1027	1028	1029	1030	1031	1032	1033	1034	1035	1036	1037	1038	1039	1040	1041	1042	1043	1044	1045	1046	1047	1048	1049	1050	1051	1052	1053	1054	1055	1056	1057	1058	1059	1060	1061	1062	1063	1064	1065	1066	1067	1068	1069	1070	1071	1072	1073	1074	1075	1076	1077	1078	1079	1080	1081	1082	1083	1084	1085	1086	1087	1088	1089	1090	1091	1092	1093	1094	1095	1096	1097	1098	1099	1100	1101	1102	1103	1104	1105	1106	1107	1108	1109	1110	1111	1112	1113	1114	1115	1116	1117	1118	1119	1120	1121	1122	1123	1124	1125	1126	1127	1128	1129	1130	1131	1132	1133	1134	1135	1136	1137	1138	1139	1140	1141	1142	1143	1144	1145	1146	1147	1148	1149	1150	1151	1152	1153	1154	1155	1156	1157	1158	1159	1160	1161	1162	1163	1164	1165	1166	1167	1168	1169	1170	1171	1172	1173	1174	1175	1176	1177	1178	1179	1180	1181	1182	1183	1184	1185	1186	1187	1188	1189	1190	1191	1192	1193	1194	1195	1196	1197	1198	1199	1200	1201	1202	1203	1204	1205	1206	1207	1208	1209	1210	1211	1212	1213	1214	1215	1216	1217	1218	1219	1220	1221	1222	1223	1224	1225	1226	1227	1228	1229	1230	1231	1232	1233	1234	1235	1236	1237	1238	1239	1240	1241	1242	1243	1244	1245	1246	1247	1248	1249	1250	1251	1252	1253	1254	1255	1256	1257	1258	1259	1260	1261	1262	1263	1264	1265	1266	1267	1268	1269	1270	1271	1272	1273	1274	1275	1276	1277	1278	1279	1280	1281	1282	1283	1284	1285	1286	1287	1288	1289	1290	1291	1292	1293	1294	1295	1296	1297	1298	1299	1300	1301	1302	1303	1304	1305	1306	1307	1308	1309	1310	1311	1312	1313	1314	1315	1316	1317	1318	1319	1320	1321	1322	1323	1324	1325	1326	1327	1328	1329	1330	1331	1332	1333	1334	1335	1336	1337	1338	1339	1340	1341	1342	1343	1344	1345	1346	1347	1348	1349	1350	1351	1352	1353	1354	1355	1356	1357	1358	1359	1360	1361	1362	1363	1364	1365	1366	1367	1368	1369	1370	1371	1372	1373	1374	1375	1376	1377	1378	1379	1380	1381	1382	1383	1384	1385	1386	1387	1388	1389	1390	1391	1392	1393	1394	1395	1396	1397	1398	1399	1400	1401	1402	1403	1404	1405	1406	1407	1408	1409	1410	1411	1412	1413	1414	1415	1416	1417	1418	1419	1420	1421	1422	1423	1424	1425	1426	1427	1428	1429	1430	1431	1432	1433	1434	1435	1436	1437	1438	1439	1440	1441	1442	1443	1444	1445	1446	1447	1448	1449	1450	1451	1452	1453	1454	1455	1456	1457	1458	1459	1460	1461	1462	1463	1464	1465	1466	1467	1468	1469	1470	1471	1472	1473	1474	1475	1476	1477	1478	1479	1480	1481	1482	1483	1484	1485	1486	1487	1488	1489	1490	1491	1492	1493	1494	1495	14
---	---	---	---	---	---	---	---	---	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	----

1	2	3	4	5	6	7	8	9	10
T	d	T	d	T	d	T	d	T	d
1255	53	1105	56.5	1510	52.5	1610	55	1725	53.5
		1530	57.5	1600	56.5	1685	57.5	1730	57.5
1230	53								

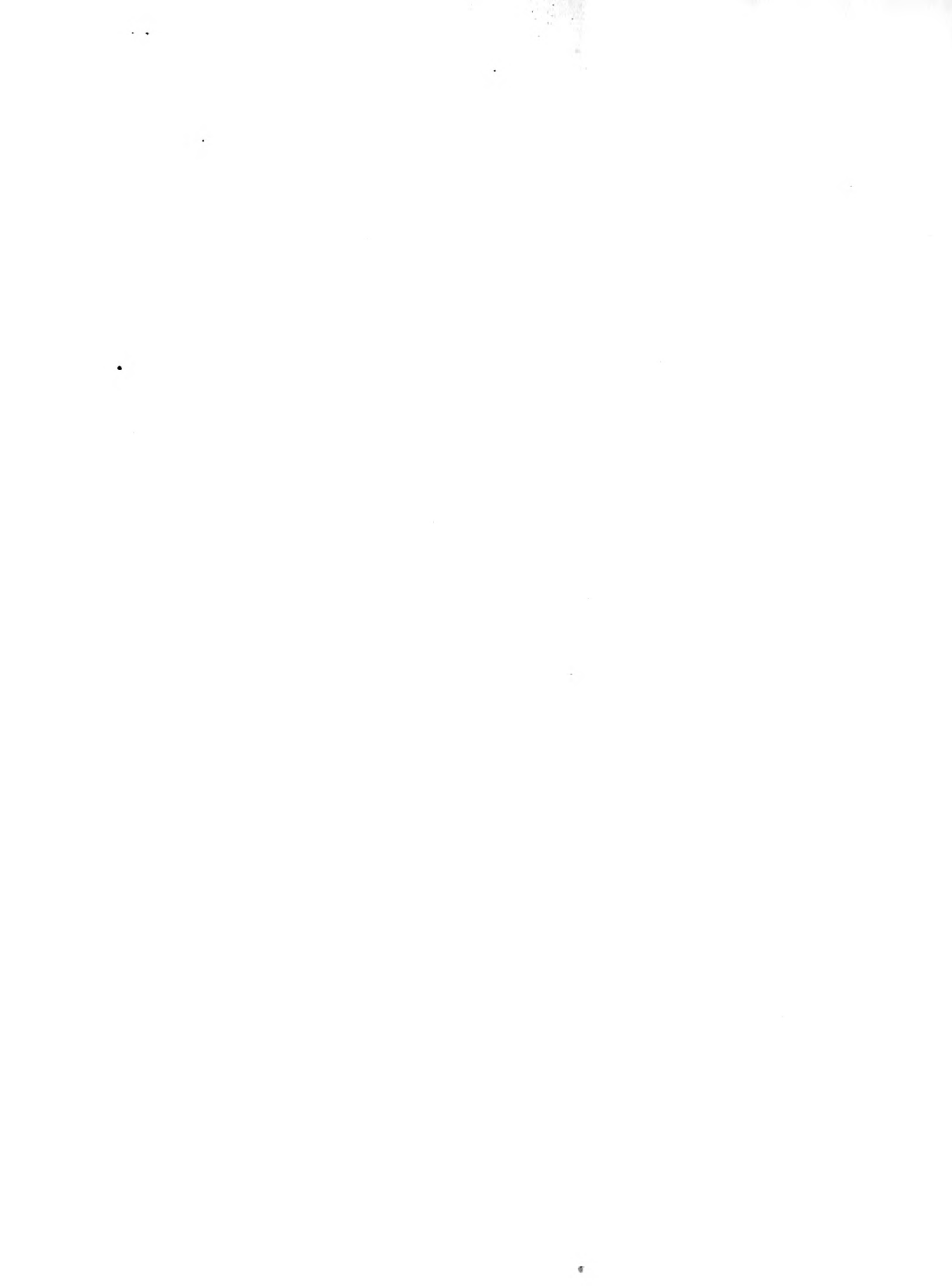
Average T. 1574
 " d. 55.54
 " v. 18.27

	1	2	3	4	5	6	7	8	9	10	
T	d	T	d	T	d	T	d	T	d	T	
1230	60.5	1235	62	1240	60	1245	60	1250	60	1255	60
1260	61.5	1265	59.5	1270	62	1275	62	1280	62	1285	62
1290	62.5	1295	62	1300	62	1305	62	1310	62	1315	62
1320	62.5	1325	62	1330	62	1335	62	1340	62	1345	62
1350	62.5	1355	62	1360	62	1365	62	1370	62	1375	62
1380	62.5	1385	62	1390	62	1395	62	1400	62	1405	62
1410	62.5	1415	62	1420	62	1425	62	1430	62	1435	62
1440	62.5	1445	62	1450	62	1455	62	1460	62	1465	62
1470	62.5	1475	62	1480	62	1485	62	1490	62	1495	62
1500	62.5	1505	62	1510	62	1515	62	1520	62	1525	62
1530	62.5	1535	62	1540	62	1545	62	1550	62	1555	62
1560	62.5	1565	62	1570	62	1575	62	1580	62	1585	62
1590	62.5	1595	62	1600	62	1605	62	1610	62	1615	62
1620	62.5	1625	62	1630	62	1635	62	1640	62	1645	62
1650	62.5	1655	62	1660	62	1665	62	1670	62	1675	62
1680	62.5	1685	62	1690	62	1695	62	1700	62	1705	62
1710	62.5	1715	62	1720	62	1725	62	1730	62	1735	62
1740	62.5	1745	62	1750	62	1755	62	1760	62	1765	62
1770	62.5	1775	62	1780	62	1785	62	1790	62	1795	62
1800	62.5	1805	62	1810	62	1815	62	1820	62	1825	62
1830	62.5	1835	62	1840	62	1845	62	1850	62	1855	62
1860	62.5	1865	62	1870	62	1875	62	1880	62	1885	62
1890	62.5	1895	62	1900	62	1905	62	1910	62	1915	62
1920	62.5	1925	62	1930	62	1935	62	1940	62	1945	62
1950	62.5	1955	62	1960	62	1965	62	1970	62	1975	62
1980	62.5	1985	62	1990	62	1995	62	2000	62	2005	62
2010	62.5	2015	62	2020	62	2025	62	2030	62	2035	62
2040	62.5	2045	62	2050	62	2055	62	2060	62	2065	62
2070	62.5	2075	62	2080	62	2085	62	2090	62	2095	62
2100	62.5	2105	62	2110	62	2115	62	2120	62	2125	62
2130	62.5	2135	62	2140	62	2145	62	2150	62	2155	62
2160	62.5	2165	62	2170	62	2175	62	2180	62	2185	62
2190	62.5	2195	62	2200	62	2205	62	2210	62	2215	62
2220	62.5	2225	62	2230	62	2235	62	2240	62	2245	62
2250	62.5	2255	62	2260	62	2265	62	2270	62	2275	62
2280	62.5	2285	62	2290	62	2295	62	2300	62	2305	62
2310	62.5	2315	62	2320	62	2325	62	2330	62	2335	62
2340	62.5	2345	62	2350	62	2355	62	2360	62	2365	62
2370	62.5	2375	62	2380	62	2385	62	2390	62	2395	62
2400	62.5	2405	62	2410	62	2415	62	2420	62	2425	62
2430	62.5	2435	62	2440	62	2445	62	2450	62	2455	62
2460	62.5	2465	62	2470	62	2475	62	2480	62	2485	62
2490	62.5	2495	62	2500	62	2505	62	2510	62	2515	62
2520	62.5	2525	62	2530	62	2535	62	2540	62	2545	62
2550	62.5	2555	62	2560	62	2565	62	2570	62	2575	62
2580	62.5	2585	62	2590	62	2595	62	2600	62	2605	62
2610	62.5	2615	62	2620	62	2625	62	2630	62	2635	62
2640	62.5	2645	62	2650	62	2655	62	2660	62	2665	62
2670	62.5	2675	62	2680	62	2685	62	2690	62	2695	62
2700	62.5	2705	62	2710	62	2715	62	2720	62	2725	62
2730	62.5	2735	62	2740	62	2745	62	2750	62	2755	62
2760	62.5	2765	62	2770	62	2775	62	2780	62	2785	62
2790	62.5	2795	62	2800	62	2805	62	2810	62	2815	62
2820	62.5	2825	62	2830	62	2835	62	2840	62	2845	62
2850	62.5	2855	62	2860	62	2865	62	2870	62	2875	62
2880	62.5	2885	62	2890	62	2895	62	2900	62	2905	62
2910	62.5	2915	62	2920	62	2925	62	2930	62	2935	62
2940	62.5	2945	62	2950	62	2955	62	2960	62	2965	62
2970	62.5	2975	62	2980	62	2985	62	2990	62	2995	62
3000	62.5	3005	62	3010	62	3015	62	3020	62	3025	62
3030	62.5	3035	62	3040	62	3045	62	3050	62	3055	62
3060	62.5	3065	62	3070	62	3075	62	3080	62	3085	62
3090	62.5	3095	62	3100	62	3105	62	3110	62	3115	62
3120	62.5	3125	62	3130	62	3135	62	3140	62	3145	62
3150	62.5	3155	62	3160	62	3165	62	3170	62	3175	62
3180	62.5	3185	62	3190	62	3195	62	3200	62	3205	62
3210	62.5	3215	62	3220	62	3225	62	3230	62	3235	62
3240	62.5	3245	62	3250	62	3255	62	3260	62	3265	62
3270	62.5	3275	62	3280	62	3285	62	3290	62	3295	62
3300	62.5	3305	62	3310	62	3315	62	3320	62	3325	62
3330	62.5	3335	62	3340	62	3345	62	3350	62	3355	62
3360	62.5	3365	62	3370	62	3375	62	3380	62	3385	62
3390	62.5	3395	62	3400	62	3405	62	3410	62	3415	62
3420	62.5	3425	62	3430	62	3435	62	3440	62	3445	62
3450	62.5	3455	62	3460	62	3465	62	3470	62	3475	62
3480	62.5	3485	62	3490	62	3495	62	3500	62	3505	62
3510	62.5	3515	62	3520	62	3525	62	3530	62	3535	62
3540	62.5	3545	62	3550	62	3555	62	3560	62	3565	62
3570	62.5	3575	62	3580	62	3585	62	3590	62	3595	62
3600	62.5	3605	62	3610	62	3615	62	3620	62	3625	62
3630	62.5	3635	62	3640	62	3645	62	3650	62	3655	62
3660	62.5	3665	62	3670	62	3675	62	3680	62	3685	62
3690	62.5	3695	62	3700	62	3705	62	3710	62	3715	62
3720	62.5	3725	62	3730	62	3735	62	3740	62	3745	62
3750	62.5	3755	62	3760	62	3765	62	3770	62	3775	62
3780	62.5	3785	62	3790	62	3795	62	3800	62	3805	62
3810	62.5	3815	62	3820	62	3825	62	3830	62	3835	62
3840	62.5	3845	62	3850	62	3855	62	3860	62	3865	62
3870	62.5	3875	62	3880	62	3885	62	3890	62	3895	62
3900	62.5	3905	62	3910	62	3915	62	3920	62	3925	62
3930	62.5	3935	62	3940	62	3945	62	3950	62	3955	62
3960	62.5	3965	62	3970	62	3975	62	3980	62	3985	62
3990	62.5	3995	62	4000	62	4005	62	4010	62	4015	62
4020	62.5	4025	62	4030	62	4035	62	4040	62	4045	62
4050	62.5	4055	62	4060	62	4065	62	4070	62	4075	62
4080	62.5	4085	62	4090	62	4095	62	4100	62	4105	62
4110	62.5	4115	62	4120	62	4125	62	4130	62	4135	62
4140	62.5	4145	62	4150	62	4155	62	4160	62	4165	62
4170	62.5	4175	62	4180	62	4185	62	4190	62	4195	62
4200	62.5	4205	62	4210	62	4215	62	4220	62	4225	62
4230	62.5	4235	62	4240	62	4245	62	4250	62	4255	62
4260	62.5	4265	62	4270	62	4275	62	4280	62	4285	62
4290	62.5	4295	62	4300	62	4305	62	4310	62	4315	62
4320	62.5	4325	62	4330	62	4335	62	4340	62	4345	62
4350	62.5	4355	62	4360	62	4365	62	4370	62	4375	62
4380	62.5	4385	62	4390	62	4395	62	4400	62	4405	62
4410	62.5	4415	62	4420	62	4425	62	4430	62	4435	62
4440	62.5	4445	62	4450	62	4455	62	4460	62	4465	62
4470	62.5	4475	62	4480	62	4485	62	4490	62	4495	62
4500	62.5	4505	62	4510	62	4515	62	4520	62	4525	62
4530	62.5	4535	62	4540	62	4545	62	4550	62	4555	62
4560	62.5	4565	62	4570	62	4575	62	4580	62	4585	62
4590	62.5	4595	62	4600	62	4605	62	4610	62	4615	62
4620	62.5	4625	62	4630	62	4635	62	4640	62	4645	62
4650	62.5	4655	62	4660	62	4665	62	4670	62	4675	62
4680	62.5	4685	62	4690	62	4695	62	4700	62	4705	62
4710	62.5	4715	62	4720	62	4725	62	4730	62	4735	62
4740	62.5	4745	62	4750	62						

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

T	d	T	d	T	d	T	d	T	d	T	d	T	d	T	d	T	d	T	d
1310	67	1360	63	1440	66	1780	64.5	1700	69.5	1940	66.5	1815	64	1015	66	1790	63.5		
1325	64.5	1325	67	1570	66	1625	64.5	1695	67	1680	66.5	1810	65	1805	67	1795	64		
		1620	62.5	1700	65.5	1735	63	1800	63	1650	65.5	1870	64	1865	67				
		1720	67			1715	64.5	1805	65			1800	65	1790	65	1740	66.5		
		1304	65.75	1342	65	1605	63.5												
		1593	65.6	1802	64.8	1810	64.75	1772	65.2	1792	64.8	1825	65.5	1797	65.3				

Average = $T = 1634$
 $d = 65.11$
 $U = 22.46$



	1	2	3	4	5	6	7	8	9	10
T	d	T	d	T	d	T	d	T	d	T
1320	68.5			1655	72	1800	62.5	1680	60.5	1865
1370	70.5	1500	60	1665	64.5	1520	71.5	1700	67.5	1710
1315	67.5	1320	69.5	1520	71.5	1640	63.5	1780	70	1925
		1375	67.5	1415	72	1765	70.5			
								1750	71	1945
										1920
										70
										68
										1745
										67.5
										1875
										69.5
										71
										2035
										71
										2060
										69

Average = $T = 1694$
 " $d = 69.57$
 " $U = 2242$

	1	2	3	4	5	6	7	8	9	10
T	d	T	d	T	d	T	d	T	d	T
1345	725	1505	745	1810	805	1015	78			
1545	81									

Average T = 1873
 " d = 79.15
 " U = 22.58

1	2	3	4	5	6	7	8	9	10
T	d	T	d	T	d	T	d	T	d
1300 844		2020 80				2160 86			
1670 84									

Average T = 1901
 " d = 86.44
 " U = 24.4



